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Emission Removal Capability of India's Forest and Tree Cover

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Abstract India is the world's tenth most forested nation with 76.87 M ha of forest and tree cover occupying 23.4% of its geographical area. Forests—with their intrinsic of carbon sequestration and storage values—are in the front line of India's climate change mitigation strategies. This paper provides estimates of sequestered carbon in India's forest and tree cover for the years 1995 and 2005 as per the IPCC good practice guidelines method. It is based on the primary data for the soil carbon pool through collecting soil samples by laying out quadrats across the country and secondary data for the growing stock of all forest and tree cover in the country. The estimates are compared with current and future projected emissions. It is found that conservation policies have resulted in increase of the country's forest carbon stocks from 6244.8 to 6621.6 Mt with an annual increment of 37.7 Mt of the carbon from 1995 to 2005. Annual CO_2 removal by the forests is enough to neutralise 9.3% of the country's 2000 level emissions. Continued removals by the forest and tree cover would offset 6.5 and 4.9% of India's projected annual emissions in 2010 and 2020 respectively. Economically, the annual value of this forest carbon in the international market is about US $188 million. The result is of use in the REDD and REDD+ context for India.

Keywords GHG Emissions · Forest Carbon Stocks · Mitigation · REDD+

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Introduction

Forests, like other ecosystems, are affected by climate change. Forests also influence climate, absorbing CO_2 from atmosphere, and storing carbon in wood, leaves, litter, roots and soil. The carbon is released back into the atmosphere when forests are cleared or burnt. By acting as sinks forests are considered to moderate the global climate. Overall, the world's forest ecosystems are estimated to store more carbon than the entire atmosphere (FAO 2006).

Deforestation, mainly conversion of forests to agricultural land, is continuing. The forest area, of about 4 billion ha (30% of the global total land area) decreased worldwide by 0.22% per year in the period 1990–2000 and 0.18% per year between 2000 and 2005 (FAO 2006). However, net loss of the forests is slowing down as a result of the planting of new forests and because of their natural expansion. Forests and trees are being planted for many purposes and at increasing rates, yet plantations still account for only 5% of total forest area (FAO 2006). Quantifying the substantial role and contribution of forests acting as carbon stores, as sources of emissions and as carbon sinks has become key to understanding and possibly modifying the global carbon cycle.

Worldwide, numerous ecological studies have been conducted to assess the carbon stocks based on carbon density of vegetation and soils (e.g. Atjay et al. 1979, Olson et al. 1983, Saugier and Roy 2001). Results of these studies are not uniform and have wide variations and uncertainties probably due to aggregation of spatial and temporal heterogeneity and application of different methodologies. IPCC (2000) estimated an average carbon stock of 86 tonnes/ha in the vegetation of the world's forests for the mid-1990s. Corresponding carbon in biomass and dead wood in the forests reported in Forest Resource Assessment (2005) amounts to 82 tonnes/ha for year 1990, and 81 tonnes/ha for year 2005. Globally, each cubic metre of the growing stock contains, on average, 1 tonne of above-ground biomass, 1.3 tonnes of total biomass and 0.7 tonne of carbon in biomass (FAO 2006). Country reports of the Food and Agriculture Organisation (FAO) indicate that global forest vegetation stores 283 Gt of carbon in its biomass, and an additional 38 Gt in dead wood. IPCC (2000) assumed 359 Gt of carbon in these pools. It is estimated that the world's forests store 638 Gt of carbon as a whole in biomass and soil (to a soil depth of 30 cm). Roughly half of total forest carbon is found in the biomass and dead wood combined, and half in the soil and litter combined (FAO 2006).

The emission removal capability of forests is generally well understood, but little literature is available on quantification aspects worldwide, probably due to lack of regional emission estimates. Britain's Forestry Commission reported 23,000 ha of forest every year for the next 40 years would reduce British greenhouse gas emissions by 10% (Benn 2009).

India is known for its diverse forest ecosystems and mega-biodiversity. It ranks as the 10th most forested nation in the world (FAO 2006), with 23.4% (76.87 Mha) of its geographical area under forest and tree cover (FSI 2008). With nearly 173,000 villages classified as forest fringe villages, there is obviously a large dependence of communities on surrounding forests. Thus, it is critical to assess likely impacts of the predicted climate change on forests, to develop and implement adaptation

strategies for biodiversity conservation and protection, for safeguarding the livelihoods of the forest dependent people, and to ensure production of roundwood for industrial and commercial needs.

Forest carbon has been assessed in various ways by many researchers. Earlier attempts for estimating forest carbon did not take into consideration soil carbon. Biomass carbon in India's forests was estimated as having been 7.94 Gt C during 1880 and nearly half of that 100 years later (Richards and Flint 1994). First available estimates for the total carbon stock (biomass and soil) for the year 1986 are in the range of 8.58–9.57 GtC (Ravindranath et al. 1997, Haripriya 2003 and Chhabra and Dadhwal 2004). FAO (2005) estimated that carbon stocks in India's forests have increased over a period of 20 years (1986–2005), and presently stand at 10.01 GtC. The stock projections for the period 2006–2030 envisage an increase from 8.79 to 9.75 GtC (IISc 2006), with forest cover becoming more or less stable and the new carbon accretions coming from the current afforestation and reforestation initiatives (Ravindranath et al. 2008). The National Communication of the Government of India to the UNFCCC for 1994 has also reported that the LULUCF sector is a marginal source of emissions, of 14.29 Mt of CO_2 per year. Notably in LULUCF, changes in the forest and other woody biomass stock account for a net removal of 14.25 Mt of CO_2 equivalent (NATCOM 2004). Thus, forests alone are a net sink.

In India, CO_2 emissions from diversion or loss of forest land are largely offset by the carbon uptake resulting in an increment in existing forests and in newly afforested areas. Many authors have concluded that the country's forests are nationally a small source with some regions acting as small sinks of carbon as well (Ravindranath et al. 1997, 2008; Haripriya 2003; Chhabra and Dadhwal 2004). Improved quantification of pools and fluxes related to the carbon cycle is necessary for understanding the contribution of forests to net emissions as well as their potential for sequestration in the context of the Kyoto Protocol (Chhabra and Dadhwal 2004).

To encourage conservation and expansion of forests world-wide, India internationally supported compensation for nations in return for the carbon services they are, and will be, providing by conserving, stabilizing and increasing their forest cover. The policy approach advocated by India in the context of the agenda item of 'Reducing emissions from deforestation in developing countries' of the United Nations Framework Convention on Climate Change (UNFCCC), also known as REDD+, was also known as 'compensated conservation' (Kishwan 2007). However, any future agreement on REDD+ would require reliable assessment and monitoring of forest carbon stocks of a country at regular intervals through application of a scientifically acceptable methodology.

The purpose of this study is to compute improved estimates for the biomass and hence the carbon in forests in India, taking into account inventory data for diversified forest types, and also by accounting for the biomass in vegetation on the forest floor other than trees. This also includes a quantitative assessment of the role of forests for emission reduction.

Research Method

Forest carbon stocks are estimated using primary data for the soil carbon pool and secondary data of the growing stock from various sources for estimating the biomass carbon following the methodology of Brown and Lugo (1984), Houghton et al. (1985) and Dadhwal and Nayak (1993). These data are used to estimate the carbon following Good Practice Guidelines of IPCC (2004). Algebraically, assessment of the carbon stocks can be represented as:

$$C_{\mathrm{Carbon}} = C_{\mathrm{Biomass}} + C_{\mathrm{Soil}}$$

where

C_{Carbon} = total available carbon in the forest, i.e., in the vegetation and in soil;
C_{Biomass} = total available carbon in the above and below-ground biomass of all forest vegetation;
C_{Soil} = total available soil organic carbon (SOC) up to 30 cm depth in the forest.

Soil Organic Carbon Pool Estimation

For estimating SOC, the IPCC guidelines (IPCC 1997) prescribe that only the upper 30 cm layer of soil, which contains the actively changing soil carbon pool in the forest, should be considered. For this purpose, representative soil samples were collected from pits 30 cm wide, 30 cm deep and 50 cm in length across the whole country during 2007 and 2008. The term *soil sample* is used here to represent one observation point in the national sampling procedure. The samples containing thoroughly mixed soil (with gravel removed) were collected from randomly selected sites from all 16 Forest Type Groups of India by digging a fresh rectangular pit and by clearing the top layer of grass, litter and humus from an area of 50 cm $\times$ 30 cm. No samples were taken from eroded land, or from near trunks of trees, roads, houses or construction sites. For estimating the bulk density, two or three clods of about 2–3 cm length were picked from each pit from top to bottom using standard procedures. These samples were collected from a total of 571 sample points laid in the various forest types covering the whole country. Forest types, a smaller part of different vegetation within the Forest Type Groups, were used as strata for sampling and up to three sample points were allocated to each stratum. Out of all samples, 15 samples falling in alpine scrub were discarded because the total area of this forest type was not known but small. Soil organic carbon and soil bulk density were estimated using the method set out by Walkley and Black (1934). All measurements and information required for each sample were systematically recorded. The bulk density (D) was defined as the weight of soil divided by volume of core (Batjes 1996), i.e.,

$$\mathrm{D} = \text{weight of soil(gm)/volume of core(cylinder) in cm}^3.$$

Soil organic carbon stock Q_i (Mg/m^2) in a soil layer or sampling level i with a depth of E_i (m) depends on the carbon content C_i (g C/g soil), bulk density D_i (Mg/m^3) and volume fraction of coarse elements G_i, leading to the formula (Batjes 1996):

$$Q_i = C_i D_i E_i (1 - G_i)$$

For the soil thickness z with k levels of departure, the total stock of carbon was obtained by adding the stock for each of the *k* levels (following Schwartz and Namri 2002):

$$C_{\text{soil}} = Q_t = \sum_{i=1}^{k} Q_i = \sum_{i=1}^{k} C_i D_i E_i (1 - G_i)$$

Rock outcrops at a site affect the representative elementary volume and the regolith volume available for root growth. This attribute was eliminated by using a simple estimate of areal percentage of the part of the rock that appears above the surface of the surrounding land to the total land area (McDonald et al. 1990).

Biomass Carbon Estimation

The biomass carbon can be disaggregated into above-ground and below-ground biomass. Change in the carbon stock during a time period is an indicator of the net emissions or removals of CO_2 in that period. Total biomass was calculated for the years 1995 and 2005, and linearly projected for the year 2015.

Assessment of biomass was based on the definition that all land parcels more than one hectare in area with a tree canopy density of more than 10% are classed as *forest*. The country's forest carbon estimate is based on the forest cover assessment of 1997, 2003 and 2005 by Forest Survey of India (FSI). The satellite data used for 1997 assessment related to the period from 1993 to 1995, and that for 2005 pertained to the period 2003–2005.

Estimates of growing stock for forest and tree cover of India for the years 2003 and 2005 are available in the State of Forest Report 2003 (FSI 2005) and 2005 (FSI 2008) respectively. However, for 1995, the growing stock only for forest cover is available at the national level. The growing stock for the tree cover for 1995 at the national level was estimated based on the mean of the ratio between the growing stock of tree cover and that of the forest cover for the years 2003 and 2005 with the assumption that between 1995 and 2005, the increment in the growing stock of the tree cover and that of forest cover have followed a uniform pattern.

Suitable biomass increment values (expansion and conversion for calculating total above-ground tree biomass) and the ratio of below and above-ground biomass (for calculating total tree biomass above and below-ground) as available in studies of Chhabra et al. (2002) and Kaul et al. (2009) covering a range of the forest types of the country were used in the present study due to non-availability of these data for entire country. These components were stem wood, branches, leaves and roots. The biomass of other vegetation on the forest floor (understory) was estimated based on the ratio of total tree biomass to total forest floor biomass excluding the tree component in the area. In general, other forest floor biomass accounts for less than 2% of total biomass of closed forest formations (Ogawa et al. 1965; Rai 1981; Brown and Lugo 1984). However, the ratio was estimated for this study based on the mean of published records for various vegetation types and localities, and also keeping in view its application and representation for the country-level estimates

from various studies (including those of Negi 1984; Rawat and Singh 1988; Singh and Singh 1985; Roy and Ravan 1996). Algebraically, the above-ground biomass of the tree component is:

$$GS_{\text{Total}} = GS_{\text{Tree}} + GS_{\text{Other Vegetaion}}$$

where GS_{Total} = total growing stock in forest

GS_{Tree} = growing stock of tree component
$GS_{\text{Other Vegetation}}$ = growing stock of other vegetation on forest floor

$$GS_{\text{Tree}} = V_{\text{Above Ground}} + V_{\text{Below Ground}}$$

$V_{\text{Above Ground}}$ = above-ground volume
$V_{\text{Below Ground}}$ = below-ground volume
$V_{\text{Above Ground}} = GS_{\text{Commercial}} \times$ expansion factor
$GS_{\text{Commercial}}$ = growing stock of tree bole up to 10 cm diameter
Expansion factor = adjusted mean biomass (volume) expansion factor for the country
$V_{\text{Below Ground}} = V_{\text{Above Ground}} \times$ ratio
Ratio = adjusted mean ratio between below and above-ground biomass (volume)

$$GS_{\text{Other Vegetaion}} = GS_{\text{Tree}} \times R$$

R = ratio of other forest floor biomass to growing stock of tree component.

The biomass is estimated by taking into account the total growing stock of the forest including the above and below-ground volume of all vegetation in the forest and multiplying it by a 'volume to mass' conversion factor. The conversion factor adopted in this study is based on the method employed in Brown et al. (1991), Rajput et al. (1996) and Kaul et al. (2009), and represented by the following formulae:

$$\text{B} = GS_{\text{Total}} \times \text{MD(Mt of biomass)}$$

GS_{Total} = total forest growing stock (Mm^3)
MD = mean wood density (t/m^3)

The biomass material contains about 40% carbon by weight, together with hydrogen (6.7%) and oxygen (53.3%) (Bowen 1979). Although most studies have used carbon proportions of between 40 and 50% depending on the wood components (e.g. Andreae 1991, 1993; Susott et al. 1996; IPCC 1997, 2004; Ludwig et al. 2003), the present study uses the conservative value of 40% carbon content keeping in view the fact that the study deals with mixed biomass comprising timber, fuelwood, leaves, twigs and roots. An average moisture content of 20% moisture content on dry basis (mcdb) in dry wood and other biomass is also assumed. This has been suggested by Leach and Gowen (1987) and Hall et al. (1994) for deriving a more realistic estimate considering that water still remains in wood even after sufficient drying. Conservative values of carbon content and mcdb have been adopted in view of the errors that are generally associated with such values and factors in computation of total growing stock, wood densities and expansion and conversion factors. Algebraically, the carbon can be estimated as:

$$C_{\mathrm{Biomass}} = \mathrm{Biomass} \times (1 - \mathrm{mcdb}) \times \mathrm{Carbon\,content\,proportion}$$

Based on the carbon estimates for the years 1995 and 2005, the annual addition of carbon in India's forest was calculated. This increment was converted into CO_2 equivalent for estimating and comparing the emissions offsetting capability of India's forests in relation to the national level GHG emissions. Figures for national emissions were obtained from published records for the year 1990, 1994 and 2000 in (Sharma et al. 2006), and for 2000, 2010 and 2020 in (Shukla 2006) with corresponding CO_2 equivalent value. The emissions removal or offsetting capability was calculated as a percentage of these projected values. Increment in forest carbon stocks over a period of time is calculated as:

Carbon Increment in m years (I_m) = C_{Carbon}in tth year − C_{Carbon} in ($t-m$)th year, and the annual increment (I_A) in forest carbon stocks is

$$I_A = \frac{I_m}{m}$$

Results

The estimates of carbon potential of India's forests as per the methodology defined above use the growing stock of the country from published reports. For the year 2005, the growing stock was estimated as 6,218 Mm^3 comprising 4,602 Mm^3 corresponding to the forest cover and 1,616 Mm^3 corresponding to the tree cover (FSI 2007). However, in 2003 the growing stock under tree cover was 1,632 Mm^3 and for the forest cover was 4,781 Mm^3 (FSI 2005). Based on these observations, the proportion of the growing stock for tree cover as compared to that for the forest cover is 35.12 and 34.14% in 2005 and 2003 respectively. The mean of these proportions (34.63%) is utilized for estimating the growing stock under tree cover for the country in the year 1995, because the figure for this growing stock for 1995 is not available. In that year, the growing stock under the forest cover was 4,339.55 Mm^3 (FSI 1997; Manhas et al. 2006), and the estimated growing stock under tree cover calculated on the basis of average proportion is 1,502.77 Mm^3, making the total growing stock of 5,842.32 Mm^3 for both forest and tree cover in 1995.

The calculation of total forest biomass uses the conversion of commercial wood volume (growing stock) into total biomass using average adjusted wood density, expansion factors and ratios. Following the methodology described, the adjusted mean biomass expansion factor (1.575), ratio between below and above-ground biomass (0.266), mean density (0.7116), and the ratio between the other forest floor biomass to the tree biomass (0.015) were estimated, and are presented in Table 1 together with calculation for the forest biomass carbon in the India's forests. Allowing for 20% moisture and 40% carbon in biomass, Indian forests captured 2,692.47 Mt of carbon in 1995 and 2,865.74 Mt in 2005.

The soil organic carbon pool for the various forest groups was estimated based on the primary data as described in methodology and reported in Table 2, yielding values of soil carbon of 3,552.3 Mt in 1995 and 3,755.8 Mt in 2003.

Table 1 Forest biomass carbon in India (Mt)

Item with symbolic description	Factor	1995	2005
Growing stock of country in Mm^3, GS		5,842.32	6,218.28
Mean biomass expansion factor, EF	1.575		
Ratio (below to above-ground biomass), RBA	0.266		
Above-ground biomass (volume), AGB = GS × EF		9,201.65	9,793.79
Below-ground biomass (volume), BGB = AGB × RBA		2,447.64	2,605.15
Total biomass (volume), TB = AGB + BGB		11,649.29	12,398.94
Mean density, MD	0.7116		
Biomass in Mt = Growing stock (Mm^3) × Mean density (MD)		8,289.64	8,823.09
Ratio (other forest floor biomass except tree to tree biomass)	0.015		
Total forest biomass in Mt (Trees + Shrubs + Herbs)−TFB		8,413.98	8,955.43
Dry weight in Mt (80% of TFB), DW		6,731.19	7,164.35
Carbon in Mt (40% of DW)		2,692.47	2,865.74

Factors for various items were derived mainly from, Singh and Singh (1985), Roy and Ravan (1996) and Kaul et al. (2009)

Based on the figures for biomass carbon and SOC in the forests reported in Tables 1 and 2, the estimates of the total carbon stock comprising components of biomass carbon and SOC for 1995 and 2005 were computed with component-wise changes, as reported in Table 3.

The analysis showed that there is an improvement in the carbon stocks from 1995 to 2005. The difference of 376.77 Mt between figures of 1995 and 2005 shows the incremental carbon accumulation in India's forests during the period. On a yearly basis, the addition of carbon was 37.68 Mt, or an annual removal of 138.15 Mt CO_2 eq. Assuming a carbon price of US $ 5/t, the annual incremental value of sequestered carbon in India's forests is US $33.11 billion with the annual incremental value of US $188 million.

Annual accumulation of the carbon stocks was compared with the trend of national GHG emissions as estimated by Shukla (2006) and Sharma et al. (2006) to estimate the proportion of national level emissions offset by forests in India. The proportion of emissions removed by India's forestry sector in various years is reported in Table 4.

Implementation of the National Mission for a Green India—designed to increase the quality and quantity of forests cover—as part of the National Action Plan for Climate Change can further enhance the present mitigation potential of the forestry sector. The methodology developed above can be used to estimate the additional quantity of carbon sequestered by afforestation and reforestation of 6 M ha of degraded forest land under the proposed Green India Mission. Assuming a conservative dry biomass accumulation of 1 *t*/ha/year, 18 Mt of carbon (in 45 Mt of dry biomass) would be accumulated by 2020 when plantations are established at the assumed rate of 1 M ha per year from 2010. The figure would rise to 75 Mt of carbon in 2025. In 2020, assuming 6 Mt of biomass containing 2.4 Mt of carbon or 8.8 Mt of CO_2eq is sequestered every year, an additional offset 0.31% of projected

Table 2 Soil organic carbon pool estimates at depth 0–30 cm in India's forests

Forest type (group)	Area 1995 (1,000 ha)	Area 2005 (1,000 ha)	Mean soil carbon	Sample number	SE	Total SOC 1995(1,000 tonnes)	Total SOC 2005 (1,000 tonnes)
Himalayan dry temperate forest	31	32	36.198	24	5.56	1,122.14	1,158.34
Himalayan moist temperate forest	2,230	2,447	71.577	48	7.16	159,616.94	175,149.17
Littoral and swamp forest	383	481	71.062	70	12.20	27,216.90	34,181.02
Montane wet temperate forest	2,583	2,593	115.460	16	14.61	298,233.29	299,387.89
Sub alpine and alpine forest	2,021	2,067	74.071	12	12.18	149,698.38	153,105.66
Sub tropical broad leaved hill forest	260	303	86.611	20	14.97	22,518.83	26,243.10
Sub tropical dry evergreen forest	1,223	1,248	65.279	3	10.37	79,836.78	81,468.77
Sub tropical pine forest	4,556	4,743	50.270	12	8.08	229,031.60	238,432.15
Tropical dry deciduous forest	18,233	19,156	34.195	143	4.16	623,475.45	655,037.33
Tropical dry evergreen forest	134	165	52.398	10	11.64	7,021.36	8,645.71
Tropical moist deciduous forest	23,091	24,284	55.009	57	6.73	1,270,222.18	1,335,848.40
Tropical semi evergreen forest	2,573	2,946	54.625	40	5.71	140,549.91	160,925.00
Tropical thorn forest	1,604	1,827	20.375	61	5.75	32,681.74	37,225.40
Tropical wet evergreen forest	5,040	5,414	101.404	40	10.04	511,078.12	549,003.37
Total	63,962	67,706		556		3,552,303.63	3,755,811.31

Table 3 Component-wise carbon in India's forests in 1995 and 2005 (Mt)

Carbon	1995	2005	Incremental change
In biomass	2,692.47	2,865.74	173.27
In soil	3,552.30	3,755.81	203.51
Total	6,244.78	6,621.55	376.77

2020 level emissions annually is predicted. The mission will have the effect of increasing the emissions removal capability of the country's forests from 4.87 to 5.18% annually of the 2020 emissions level. Even if half the biomass of 3 Mt from the total annual incremental biomass is removed from 2025 onwards on a sustainable basis, the plantations of the National Mission would still be able to maintain the increased emissions removal capability of the forestry sector at 5.02% of 2020 level emissions.

Table 4 Total GHG emissions from various sectors and proportion thereof offset by forestry sector (Mt CO_2 eq)

Source	Variable	Proportion				
		1990	1994	2000	2010	2020
Shukla (2006)	Total GHG emissions	–	–	1,454	2,115	2,839
	Proportion removed by India's forestry sector (%)			9.50	6.53	4.87
Sharma et al. (2006)	Total GHG emissions	987.89	1,228.54	1,484.62	–	–
	Proportion removed by India's forestry sector (%)	13.98	11.25	9.31		

Conclusions

Properly managed forests backed by appropriate policies, investment and research offer a potential mitigation option towards climate change. A challenge arises for countries that have substantial forest resources but also a sizable rural population that is dependent on the goods and services from forests for livelihood support. How to conserve, improve and expand the forests in face of conflicting demands of protection of the environment, and at the same time, concern for the rapid development, is the key question. If with the present level of investment, and despite high dependence of rural communities on it, the forestry sector in India is capable of offsetting 9.3, 6.5 and 4.9% of emissions in 2000, 2010 and 2020 respectively. It can provide a still greater mitigation service provided the investment rises and the dependence of people on the sector is reduced by making available to them alternative sources of the forest and tree products. The National Mission for a Green India, providing LPG, biogas plants and energy efficient stoves to mountain people of Himalayan region and Western Ghats, and strengthening the protection regime of the forests, can increase the carbon sequestration potential of forest and tree cover in India.

The results also provide an approach for other developing countries, which they can use for estimating the carbon stocks in forest and tree cover, and designing investment and policy strategies to improve the potential and quality of the mitigation service ensuing from the sector. Such country specific information may also be used for negotiations to REDD+ issues.

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